The Distribution and Population Dynamics of the Golden Mouse
(*Ochrotomys nuttalli*) at Its Southern Range Periphery

Sarah A. Smiley
*University of South Florida*

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The Distribution and Population Dynamics of the Golden Mouse

(*Ochrotomys nuttalli*) at Its Southern Range Periphery

by

Sarah A. Smiley

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science
Department of Integrative Biology
College of Arts and Sciences
University of South Florida

Co-Major Professor: Earl D. McCoy, Ph.D.
Co-Major Professor: Henry R. Mushinsky, Ph.D.
Gordon A. Fox, Ph.D.

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To my parents, who have given their love and support.

This is possible because of you.
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The Distribution and Population Dynamics of the Golden Mouse
(\textit{Ochrotomys nuttalli}) at its Southern Range Periphery

Sarah A. Smiley

ABSTRACT

This research assesses the status of the golden mouse (\textit{Ochrotomys nuttalli}) in Florida by taking a multi-pronged approach. Geographic Information Systems (GIS) was used to understand the distribution of habitats and occurrence records for this species within the state. Presence-absence trapping occurred at 13 study sites to determine if historic southern periphery populations were still occupied, gauge if more central populations were being maintained, and document golden mice in previously unrecorded areas. In addition, surveys for \textit{O. nuttalli} took place at regular intervals at the USF Ecological Research Area to understand how populations of this species fluctuate over time and ensure that individuals could be caught during the months when statewide trapping was occurring. Trapping data from all 14 sites were combined to determine a level of confidence for absences at each site which did not yield a golden mouse capture. Finally, I determined the relative abundance of golden mice relative to other small mammal species caught. Locality records for this species align closely with the distribution of hardwood-containing habitats in Florida. The distribution of \textit{O. nuttalli} is not continuous across Florida and becomes increasingly patchy near the southern range periphery of this species. In south-central Florida, populations are restricted to regions where hardwoods extend south along one of three upland ridges. Golden mice were determined to be
present in the vicinity of the southernmost historic sites on each of these ridges. 

*Ochrotomys nuttalli* were captured at six of the 13 sites surveyed. At the USF Ecological Research Area, *O. nuttalli* were captured in all months surveyed although abundances remained relatively low from October through January and then increased from February through May. At study sites which did not catch a golden mouse, 78.6 to 100% of the trapping periods which successfully caught a golden mouse had done so by the effort levels invested at these absent sites. *Ochrotomys nuttalli* was the fourth most abundant of 12 species captured, but several of the species caught less frequently than golden mice are non-native or too large to have their true abundance reflected by these trapping methods.
Introduction

A geographic range basically is “a description of the regions in which a species has been recorded” (Gaston 1991). Geographic ranges can be measured in terms of extent of occurrence and area of occupancy. Extent of occurrence is the smallest area contained within an imaginary polygon drawn to include all locality records of an organism; it may include areas that are not currently occupied by the species or habitat regions that are unsuitable for the organism of interest (Gaston 1991). Area of occupancy accounts for the pockets of non-occurrence that fall within the extent of occurrence (Gaston 1991). No matter how a geographic range is measured, changes in range size can occur as a result of habitat alteration caused by humans (Lomolino and Smith 2001; Ceballos and Ehrlich 2002) and climate change (Parmesan et al. 1999; Moritz et al. 2008). In landscapes that are being modified at a fast rate, populations of species may become highly fragmented, subject to the effects of low population size, and eventually extirpated. At the periphery of a species’ geographic range, individuals may already be stressed by living near their physiological limits and it may not take much additional stress for them to succumb to external pressures. The end result could be a contraction in the species’ geographic range.

The conservation status of a species is determined by the distribution and abundance of the species and the change in these measures of commonness over time (McGowan, Gillman, and Dodd 1998). Thus, to determine the conservation status of
species, distributional data over time are of particular importance. Unfortunately, systematically-collected distributional data are becoming increasingly difficult to find at a time when assessing conservation status and maintaining biodiversity are of great concern (Schipper et al. 2008). Natural historians are less prevalent than they were 60 years ago (Schmidly 2005; Hafner 2007) and biological monitoring conducted by government agencies has been reduced because of insufficient funding to maintain such programs (Smiley 2008).

This study aims to assess the status of the golden mouse (*Ochrotomys nuttalli* Harlan, 1832) in Florida using distribution and abundance data. The golden mouse is a mid-size cricetine rodent whose geographic range largely coincides with the extent of the deciduous (oak-hickory) hardwood and pine forest of the southeastern United States (Packard 1969). South-central Florida is the southern range periphery of this species. Five subspecies of *O. nuttalli* are recognized based on the habitat region where individuals are collected (i.e. coastal plain, piedmont, mountains) as well as pelage and morphological variation of museum specimens (Packard 1969). The subspecies *O. nuttalli floridanus* is found in the northern two-thirds of Florida, except for the region of the Florida panhandle west of the Apalachicola River where *O. nuttalli nuttalli* occurs.

Like most small mammals, *Ochrotomys nuttalli* is mainly crepuscular and nocturnal (Linzey and Packard 1977). Golden mice are semi-arboreal, using their semi-prehensile tails, stomach musculature, and well developed plantar tubercles to move around above ground level in thick vegetation. *Ochrotomys nuttalli* build arboreal nests in some habitats (Linzey and Packard 1977). They have a preference for thick shrubby habitats (Stelljes 1982; Wagner, Feldhamer, and Newman 2000). The structure of
preferred *Ochrotomys* habitats is sufficiently overgrown so as to challenge human movement through them. Although this species occurs over a relatively large geographic area (Feldhamer and Morzillo 2008) and occupies several habitat types (Linzey and Packard, 1977), it is usually highly selective at the microhabitat scale (Wagner, Feldhamer, and Newman 2000). *Ochrotomys nuttalli* prefer some stages of succession over others. In the central and northern portion of their range, golden mice tend to be more common in early to mid-successional forests where saplings, shrubs, and vines are present (Seagle 2008), while in southern populations they are more abundant in the later stages of succession when leaf litter, vines, and Spanish moss (*Tillandsia usneoides*) accumulate in the absence of fire (Landers and Crawford 1995). Overall, golden mice tend to be the most abundant in habitats which support the thickest underbrush vegetation for the region.

*Ochrotomys nuttalli* are typically found in densities much lower than sympatric *Peromyscus* species (Feldhamer and Linzey 2008; Rose 2008). Densities of golden mice, as summarized by Linzey and Packard (1977) as well as Rose (2008), range widely from 0 to 74.1 individuals per hectare. In a review of 26 density estimates found in the literature, Rose (2008) reported a median of 4.3 individuals per hectare. Much of the variation in density estimates may be attributed to whether or not researchers established their study grids within habitat optimal for golden mice (Rose 2008). *Ochrotomys nuttalli* often have patchy distributions (Rose 2008) and live in highly localized populations (Feldhamer and Linzey 2008). Thus, density estimates that include or exclude these concentrations of individuals would lead to very different results. Density estimates also will vary with season. In the south, *O. nuttalli* attains its highest densities
in the winter (McCarley 1958) and data generally support a winter breeding season in southern populations (see Rose 2008).

*Ochrotomys nuttalli* is not a species of conservation concern over the majority of its range with the exception of the peripheral states of West Virginia (rank of S2: Six to 20 documented occurrences or few remaining individuals within the state; very rare and imperiled) and Illinois (threatened). In Oklahoma, golden mice are a species of greatest conservation need. In sum, the golden mouse is seldom targeted for monitoring. Because it is nocturnally active above ground, highly selective of thick and unpleasant to sample habitats, patchy in distribution, and low in relative abundance, the golden mouse is an organism that is rarely encountered while conducting surveys for other species; it requires a species-specific sampling regime.

In Florida, reports of *O. nuttalli* captures are infrequent and incidental. Locality data for the state have not been centralized beyond the extent of museum specimen databases. This is a species whose changes in distribution and abundance over time have gone largely unmonitored, especially at the southern extent of its range. The conservation status of the golden mouse in Florida is described as “not ranked/under review” by Feldhamer and Morzillo (2008), signaling the general lack of data that have been collected for this species in the state. Despite these challenges, assessing the distribution and conservation status of *O. nuttalli* in Florida is of importance because widespread habitat loss has been occurring in the state. Landscape level changes of natural areas to urban centers, suburban sprawl, agricultural fields, and large scale mining operations has been brought about by the pressures of a burgeoning human population. To exemplify the magnitude of the changes seen over the past quarter century, the human
population of the state was estimated by the U.S. Census Bureau at 9,746,342 individuals in the 1980 census, but has grown to 18,251,243 persons in 2007, a population increase of 87% in 27 years (United States Census Bureau).

The objective of this study was to assess the status of the golden mouse in Florida. I compared the current geographic range of *Ochrotomys nuttalli floridanus* to that of historic records focusing on the extent of occurrence and examined the level of fragmentation between existing populations by looking at the distribution of suitable habitats in the state. In addition, I documented the abundance of *O. nuttalli* relative to other small mammals captured in this study as a means of describing rarity at the population level—one of three types of rarity used to classify organisms (Rabinowitz et al. 1986; McCoy and Mushinsky 1992). I utilized Geographical Information Systems (GIS) as well as small mammal live trapping techniques to address these objectives.
Methods

Determining the Geographic Range of Golden Mice and Distribution of Habitats Using Geographic Information Systems (GIS)

To determine if the distribution of *Ochrotomys nuttalli floridanus* has shifted from historic data, it was first necessary to establish a baseline using historic occurrence records of *Ochrotomys nuttalli floridanus* and its potential habitats. ArcGIS 9.2 (ESRI, Redlands, CA) was used to construct a map (Figure 1) showing the historic distribution of golden mice and the natural fragmentation of suitable habitats within the state. This map also served to visualize how closely locality records were aligned with specific habitat types and identify areas with appropriate habitat that lacked *O. nuttalli* records for trapping in the field. Next, changes to this historic distribution were examined using current land use data. A second map (Figure 2) was developed to estimate changes in the historic occurrence of habitat types in south-central Florida and how these landscape-level changes further fragment *O. nuttalli* populations already existing in a patchy environment.

To create these maps, records of *O. nuttalli floridanus* (n=195) were accumulated from various sources including museum specimens, personal communications, literature survey (Packard 1969, Pinkham 1971), and live trapping in the field (see subsequent sections for trapping details). Museum specimens used were those from the Florida Museum of Natural History (FLMNH), the Florida State University (FSU), Tall Timbers
Research Station (TTRS), and the Smithsonian National Museum of Natural History (NMNH). It was assumed that the current range is probably a subset of the historic range and so all new localities identified from field work under this project were included in the historic range estimate.

Land use data layers, including a 1967 distribution of the vegetative communities of Florida, locations of shopping centers, and developments of regional impact (DRIs), were downloaded from the Florida Geographic Data Library (http://www.fgdl.org/, accessed March 2007). These layers, along with latitudes and longitudes of the golden mouse locations, were imported into ArcGIS 9.2. Each feature class of the 1967 vegetative communities of Florida was exported into a separate data layer. Habitats were then placed into one of three categories (inappropriate, marginal, and appropriate) based on the suitability of that habitat type for golden mice. Categorization was done using an educated opinion built upon experience trapping in the field and the known preference of the golden mouse for habitats with a thick shrubby component (Stelljes 1982; Wagner, Feldhamer, and Newman 2000). Data within each category were merged with the resulting layers: 1) inappropriate habitat: includes urban, mangrove coastal marsh, cypress swamp, southern slash pine, scrub cypress, rockland marshes, Everglades wet prairie, Everglades sawgrass, freshwater marsh, and prairie grasslands, 2) marginal habitat: pine flatwoods and cabbage palm forest, 3) appropriate hardwood-containing habitats: hardwood swamps, longleaf pine-xeric oak, sand pine scrub, mixed hardwoods and pine, hardwood forest, and coastal strand, and 4) bodies of water.

A probable historic range map of *O. nuttalli floridanus* was constructed by placing an 80 kilometer (km) buffer around each locale record and dissolving these
buffers into one occurrence layer. As museum records were concentrated around the institution of origin, the addition of a buffer around locality records helped compensate for under-sampling in some regions. The buffer was set at 80 kilometers because this was the minimum distance at which under-sampled areas not questioned to be within the range of *Ochrotomys* -- in the center of the state and along the Georgia border --were included in the analysis. Next, this occurrence layer was intersected with two habitat layers, the first containing only hardwood habitats and the second including marginal habitats, as previously defined. This intersection of occurrence data and habitat layers generated the final distribution map (Figure 1).

A more updated (current) range map was developed by taking the historic habitat data layers and erasing natural habitat lost to urbanization and mining uses. Developments of regional impact (DRIs) were used to approximate land lost to mining, while a layer of dissolved 1.6 kilometer buffers around shopping centers represented urban centers. A buffer around shopping centers was utilized to reflect urban areas in preference of commercially available urban area layers because it permitted patches of suitable habitat to remain within urban boundaries; this coincides with known *O. nuttalli* populations persisting in natural reserves surrounded by urban development such as the University of South Florida’s Ecological Research Area (USF Eco Area). Erasing these anthropogenic land uses from the historic map created a probable current distribution of *O. nuttalli* in Florida. As this distribution ignores conversion of habitat to land uses other than urban and mining (such as agricultural), it is intended to be a conservative estimate of habitat loss. Shown in Figure 2 is a subset of the range map that was developed as land use changes were most pronounced in the south-central region of Florida.
Temporal Changes in Abundance

To assure that *Ochrotomys nuttalli* were able to be captured in all months during which state-wide surveying was occurring (discussed below), the abundance of golden mice was monitored over a 7.5 month period (October 2007 – May 2008) at a location where *O. nuttalli* was known to occur. Monitoring took place at the University of South Florida’s Ecological Research Area (USF Eco Area) (latitude = 28.07, longitude = -82.38), a preserve of sandhill, overgrown scrub, flatwoods, and cypress habitats that is surrounded on at least three sides by suburban development in north Tampa. Sherman live traps (dimensions: 22.9cm x 8.9cm x 7.6cm, H.B. Sherman company, Tallahassee, FL) were placed in pairs (hereafter referred to as a “trap station”) in habitat that had been previously identified as containing *O. nuttalli* by trapping conducted in January and March 2007. A total of 120 traps were placed at 60 trap stations (Figure 3). Trap stations were minimally spaced 10m apart and placed to maximize captures within the heterogeneous habitat. Traps were baited with a mixture of sunflower seeds and rolled oats, set each evening, and checked and closed just after sunrise. Trapping occurred over a period of four consecutive nights (hereafter, a “trap period”) and except for October to November was conducted at monthly intervals. Dates of trapping were October 20-24, November 3-7, December 1-5, January 6-10, February 3-7, March 2-6, April 6-10, and May 4-8. Each trapping period consisted of 480 trap nights (a measure of effort equal to the number of traps set out times the number of nights they were open) for a total of 3,840 trap nights over the 7.5 month period.
All captured mice, rats, and squirrels were identified to species, sexed, ear tagged (Monel, size 1005-1, National Band and Tag, Newport, KY), and released at the point of capture. Captured shrews were weighed, measured, and released at the place of capture. Captured *Ochrotomys nuttalli* also were weighed and subject to genetic tissue sampling (see Smiley et al., in review) prior to release.

**Assessment of Current Extent of Occurrence**

Presence/absence surveying was conducted around the state of Florida between November 2007 and May 2008, with a focus on the southern periphery of *Ochrotomys nuttalli*’s range. The primary goal of the survey was to determine if the southern range periphery of *O. nuttalli* had shifted from the historic locale data. The most likely direction of a shift would be the contraction of *O. nuttalli*’s extent of occurrence northward resulting from increased fragmentation of the landscape and the resulting extinction of isolated populations. Ancillary goals were to determine if documented populations more central to the range were being maintained (reflecting a stable area of occupancy), to document previously undescribed populations in areas determined to have suitable habitat by the GIS model, and to determine the abundance of *O. nuttalli* relative to that of other small mammals captured. The presence or absence of *O. nuttalli* was determined on each property visited using direct and indirect measures. Direct evidence of golden mice on site was obtained from live trapping and indirect evidence came from searching for arboreal nests.

To assess if the southern range periphery of the golden mouse was stable, the southernmost documented locales along the east coast, central ridge, and west coast were
identified from accumulated location data. These southernmost locales are Little Manatee River – South Fork State Preserve (also known as the Beker Parcel) in north Manatee County, Archbold Biological Station (ABS) in Highlands County, and 5 miles south of Melbourne Beach in Brevard County. *O. nuttalli* were last documented at South Fork State Preserve in 1990 by state biologist Terry Hingtgen (Florida State Parks, District 8 annual report), at ABS in 1998 by Richard Lavoy (personal communication), and at south Melbourne Beach in 1945 from a specimen at the Florida Museum of Natural History (catalog number 2723).

Accessible lands that were in close proximity to these three southern sites were surveyed in 2008 to determine the current extent of *Ochrotomys nuttalli*’s range (Figure 4; Table 1). On the west coast, trapping was performed at Southwest Florida Water Management District’s (SWFWMD) Little Manatee River Southfork Tract (LMRSF), a property adjacent to the south boundary of South Fork State Preserve. On the central ridge, trapping occurred directly on ABS, including some of Jim Layne’s former grids (for a description see Packer and Layne 1991). On the east coast, the habitat in the vicinity of Melbourne Beach has become quite fragmented in recent years. Trapping in this area occurred on small, scattered undeveloped parcels that are a part of Brevard County’s Environmentally Endangered Lands Program (EELP) including Coconut Point Preserve (25.1 hectares), Maritime Hammock Preserve (56.7 hectares), and the Washburn Property (15.8 hectares). In addition to surveying for *O. nuttalli* on the barrier island near Melbourne Beach, trapping also occurred at approximately the same latitude on the mainland at Brevard County’s EELP Malabar Scrub Property in an area of the county where the landscape was less developed.
Nine additional sites across peninsular Florida were surveyed to determine if the area of occupancy of golden mice was stable, document previously unknown locality records, and assess the relative abundance of *O. nuttalli* (Figure 4; Table 1). Six of these sites were within the historic extent of occurrence (with county of Florida indicated where appropriate): Hillsborough County’s Balm Boyette Scrub, Brevard County’s Indian Mounds, Faver Dykes State Park (St. Johns), The Nature Conservancy’s Tiger Creek (Polk), SWFWMD’s Jack Creek (Highlands), and Wekiwa Springs State Park (Orange). Additionally, three sites were trapped in the southwest portion of the state outside the documented range of this mouse, but within habitat identified as marginal by the GIS model. Trapping was performed in this portion of the state to ensure that *O. nuttalli*’s apparent absence here was not caused by lack of monitoring. The properties surveyed were Lee County’s Hickey’s Creek Mitigation Park, Charlotte County’s Shell Creek, and SWFWMD’s Deep Creek (Desoto County). It would have been ideal to survey for golden mice in the region between north Manatee and south Desoto Counties (between LMRSF and Deep Creek) particularly in Hardee and Desoto Counties where hardwood habitats extend south along the Peace River corridor, but the lack of public lands and a growing mining pressure in this region limited where trapping could occur.

At all sites, traps were placed in habitats that were visually deemed the most suitable for golden mice compared to what was available at each location. Traps were baited with a mixture of sunflower seeds and rolled oats in the same manner as at the USF Eco Area. Captured small mammals were identified to species, sexed, given a short term mark by fur clipping, and released at the point of capture. *Ochrotomys nuttalli* that were caught were also weighed and subject to genetic tissue sampling prior to release.
The number of trap nights accumulated per site depended on a number of factors including travel distance to site, weather, study site policies (state parks were not accessible on weekends), amount and layout of favorable habitat, and density of small mammals (in warm weather and in areas of high trap success it becomes difficult to process all animals before heat mortalities occur). Trapping dates and the number of trap nights for the ten sites within the previously documented range are detailed in Table 1. Dates of trapping and amount of effort for those in the southwest portion of the state were as follows: Hickey’s Creek Mitigation Park (December 19-24, 2007) 573 trap nights, Shell Creek (December 26-31, 2007) 536 trap nights, and Deep Creek (January 19-23, 2008) 411 trap nights. In summary, a total of 5,723 trap nights were conducted in search of *O. nuttalli* at thirteen sites across peninsular Florida.

The following procedures were performed to assign a level of confidence to the determination of absence at study sites on which live trapping did not result in the capture of *Ochrotomys nuttalli*. First, the effort until first capture (expressed in trap nights) was determined for all fourteen trapping periods in which golden mice were caught. This effort was then plotted as the percentage of ‘present’ trapping periods which resulted in a capture by a given quantity of effort (Figure 5). Next, the total effort (in trap nights) was calculated on absent sites. Finally, each absent site was assigned a percentage of the present trapping periods which yielded a golden mouse capture at or below the effort expended on the absent site (Table 2). These steps were repeated for both uncorrected and corrected trapping efforts. Corrected efforts were calculated by taking the uncorrected effort and subtracting one-half times the number of traps that were closed in the morning which did not contain *O. nuttalli*. This correction was intended to adjust the
effort expended on study sites where non-target species were ubiquitous or traps were tripped by raccoons (*Procyon lotor*) or other animals (for more information on correction factors see Nelson and Clark 1973 and Beauvais and Buskirk 1999). These events would lower the likelihood of catching *O. nuttalli*.

In addition to live trapping for *Ochrotomys nuttalli*, indirect evidence of their presence was obtained from arboreal nests found on study sites. Although no formal surveys for the nests were conducted because it was not known how common or identifiable these structures would be at the onset of the study, places where nests were found indicated that *O. nuttalli* was likely present there at least in the recent past.

*Relative Abundance of the Golden Mouse*

Relative abundance data was examined in order to compare population numbers of *Ochrotomys nuttalli* to sympatric species, in essence trying to assess if the golden mouse is relatively rare at a local level. The relative abundance of individuals of each small mammal species captured was examined for the eleven study sites which fall within the documented range of *Ochrotomys nuttalli*. These relative abundance data are based on a combined effort of 8,043 trap nights. Bar graphs in which species were ranked from most to least common were constructed twice- once for all study sites and again using only those sites where *O. nuttalli* were captured.
Results

*Determining the Geographic Range of Golden Mice and Distribution of Habitats Using Geographic Information Systems (GIS)*

Recorded occurrences of *Ochrotomys nuttalli* align closely with the distribution of hardwood-containing habitats in Florida (Figure 1). GIS places most locales (146 of 195) directly within hardwood-containing habitats and 48 of the remaining 49 locales within 4 km of this vegetation class (mean distance = 1.82 km, median distance = 1.13 km). Chuluota Wilderness Area in Seminole County is the location furthest from the nearest appropriate hardwood-containing habitat at a linear distance of 10.3 km (Figure 1).

As depicted in the 1967 vegetation data layer, hardwood-containing habitats have a non-continuous distribution in the northern two-thirds of Florida (Figure 1). At the golden mouse’s southern range periphery in south-central Florida, these vegetation types occur in patches usually surrounded by a matrix of pine-palmetto flatwoods. The east coast of Florida contains a long, narrow stretch of hardwood habitat (on the Atlantic Coastal Ridge) that is isolated from other such vegetation types. As the distribution of hardwood-containing habitats in Florida is naturally fragmented and *Ochrotomys nuttalli* locality records are closely aligned with these vegetation types, the distribution of the golden mouse in Florida should also be non-continuous. This distribution is reflected in the occurrence data. *O. nuttalli* are found approximately two-thirds of the way down the peninsula and have an interrupted distribution from east to west within this region that
coincides with the prevalence of appropriate habitat patches. The most isolated occupied hardwood patch is LMRSF, a site on the west side of the peninsula at the range periphery of *O. nuttalli* (Figure 4). The golden mouse population at LMRSF is 12.8 km from another hardwood habitat patch and 21.4 km from a hardwood patch that is known to contain *O. nuttalli* (Balm-Boyette Scrub). Golden mice found on Atlantic Coastal Ridge at Malabar Scrub (Figure 4) are historically connected to other populations north (and possibly south) along the coast, but are approximately 74 km linear distance from the large patch of hardwood-containing habitat found at the same latitude on the central ridge.

The addition of urban and mining land use categories to the map of *Ochrotomys nuttalli* occurrence records has the effect of making naturally fragmented southern periphery populations even more isolated (Figure 2). Although changes in land use have led to all populations becoming increasingly isolated from one another, the effects are most dramatic in two regions of the state: the Atlantic Coastal Ridge on the east coast and Bone Valley – an area of extensive phosphate mining in Polk, Hardee, Hillsborough, and Manatee Counties to the west of the central Lake Wales Ridge. Urban development and sprawl on the Atlantic Coastal Ridge has broken the narrow north-south linkage that historically existed between coastal populations. Southern populations such as those at Malabar Scrub are no longer connected to northern populations by either hardwood-containing or marginal habitats. Meanwhile in Bone Valley, mining developments of regional impact have been the greatest perpetrator in reducing hardwood habitats in the region. Large scale mining not only reduces available habitat for local populations (one locality record lies in the midst of a development of regional impact (DRI)), but has the
effect of making west coast *Ochrotomys nuttalli* more isolated from those inhabiting the central ridge.

*Temporal changes in abundance*

*Ochrotomys nuttalli* were captured during all trapping periods at the USF Eco Area. The abundance of individuals varied over time (Figure 6). The number of individuals captured during each trap period remained relatively low from the beginning of the study in October 2007 through January of 2008, with only two to three individuals caught during these months. Similarly, the capture rate (including recaptures) was minimal for this period ranging from 0.0042 to 0.0104 golden mice per trap night. Beginning in February 2008 through the end of the study in May 2008, the number of golden mice increased with each successive trap period. Twelve individuals were caught in February, 16 in March, 24 in April, and 26 in May. Capture rates (including recaptures) increased accordingly, going from 0.0354 golden mice per trap night in February to 0.1021 golden mice per trap night in May, about an order of magnitude larger than in the fall and early winter. New individuals were basically non-existent in the traps prior to February 2008 (captured marked individuals were tagged in January or March 2007), after which time between 7 and 11 new individuals were caught each month. A total of 39 individuals were captured 162 times over the course of study at the USF Eco Area for an across-month average capture rate of 0.0422 golden mice per trap night (Table 1). These results confirm that *O. nuttalli* were able to be captured during all months when state-wide surveys were taking place.
Assessment of current extent of occurrence

*Ochrotomys nuttalli* were captured at six of the thirteen statewide locations that were surveyed (Figure 2; Table 1). In focusing on the southernmost sites, the presence of *O. nuttalli* was first confirmed at LMRSF on the west coast. At this site, five individuals were captured seven times in 464 trap nights for a capture rate of 0.0151 mice per trap night. On the central ridge, no golden mice were caught at ABS despite considerable effort here (976 trap nights), but arboreal nests were observed on station. Further support for possible low densities of *O. nuttalli* present on ABS is that golden mice were documented at the Lake Placid Scrub, a preserve that lies just north of ABS, in 2008 (H. Hoffman, personal communication). On the east coast, *O. nuttalli* was not captured on any of the three small properties surveyed to the south of Melbourne Beach (482 trap nights). The habitat present on this barrier island at the time of field work consisted mostly of maritime hammock with sparse understory, exotic plants or areas where exotics had been cleared, and a patch of recently burned coastal scrub. On the mainland, trapping was successful at Brevard County’s Malabar Scrub where six individuals were captured six times in 456 trap nights for a capture rate of 0.0132 mice per trap night. In summary, *Ochrotomys nuttalli* were found to be present in the vicinity of each of the southernmost documented localities in 2008.

*Ochrotomys nuttalli* were also captured at Hillsborough County’s Balm-Boyette Scrub (one individual), The Nature Conservancy’s Tiger Creek (one individual), SWFWMD’s Jack Creek (four individuals), and Brevard County’s Indian Mounds (four individuals). Balm-Boyette Scrub was a confirmation of a previous record, while golden mice had not been documented before at the remaining three sites. *Ochrotomys nuttalli*
were not found at Faver-Dykes State Park and Wekiwa Spring State Park, however arboreal nests were identified at the former. These state parks both had previous records of golden mice and the amount of effort invested at each was low (266 and 233 trap nights, respectively). Faver-Dykes and Wekiwa Spring are fairly large parks, preserving 2,446 and 3,157 hectares, respectively. The results of presence-absence trapping for the eleven study sites that lie within the documented range (including the USF Eco Area) are summarized in Table 1 and Figure 2.

*Ochrotomys nuttalli* were not found at any of the locations surveyed in the southwest portion of the state that lie outside of the documented range (Deep Creek, Shell Creek, and Hickey’s Creek), despite on the ground verification of oak species (*Quercus* sp.) occurring along the stream corridor of each site. Hickory species (*Carya* sp.) were also present at Shell Creek.

On study sites where *Ochrotomys nuttalli* was found to be present using live traps, the first capture of a golden mouse in a trapping period occurred with an uncorrected effort ranging from 50 to 442 trap nights. Corrected effort at first capture ranged from 35 to 420 trap nights. The percentage of trapping periods with a first capture occurring by an invested amount of effort is shown in Figure 5. A large percentage of trapping periods had a first capture with a relatively low amount of effort. For example, 79% of trapping periods in which a golden mouse would be caught had already documented the species as present at an effort of 146 uncorrected trap nights. At 278, 318, and 442 uncorrected trap nights, 86%, 93%, and 100% of trapping periods respectively had caught *O. nuttalli*. Correcting effort for closed traps leads to a faster accumulation of the percentage of trapping periods (Figure 5). At sites where *O. nuttalli* was absent, all had an invested
effort greater than 150 trap nights and five of the sites had an uncorrected effort greater than 400 trap nights. Thus, a great amount of confidence can be placed in the fact that either *O. nuttalli* is indeed absent from the sites where they were not caught or that they occur there in exceedingly low densities. Table 2 details the percentage of trapping periods which yielded a golden mouse capture at or below the effort expended on each absent site.

Arboreal nests were seen at all the sites where golden mice were caught, with the exception of Hillsborough County’s Balm-Boyette Scrub. In addition to nests seen at study sites where *Ochrotomys nuttalli* were present, arboreal nests were identified at two locales where *O. nuttalli* were not captured – Archbold Biological Station and Faver-Dykes State Park. Nests identified as likely built by golden mice were constructed primarily of saw palmetto (*Serenoa repens*) fibers. At Brevard County’s Indian Mounds, several nests with a similarity in appearance to those seen at other locations were found to be active, with golden mice flushing from them when disturbed.

The culmination of evidence from GIS mapping, presence-absence surveying, and nest surveying, indicates that the range of *Ochrotomys nuttalli* has not experienced any substantial northward latitudinal shift over the past 70 years. However, hardwood habitat patches are becoming increasingly isolated from one another in south-central Florida and some local populations of golden mice, such as those at Melbourne Beach and in Bone Valley, have likely been extirpated as a result of modifications to the landscape.
Relative abundance of the golden mouse

Three small mammal species dominated the 1,217 individuals that were captured across the eleven study sites within the documented range of the golden mouse, including the USF Eco Area (Figure 7). The Florida mouse (*Podomys floridanus*), the cotton mouse (*Peromyscus gossypinus*), and the hispid cotton rat (*Sigmodon hispidus*) accounted for combined 93.2% of all individuals. *Podomys floridanus* were far more abundant than any other species where they were present with 512 individuals caught at six different locales. *Peromyscus gossypinus* were the second most frequently caught species, totaling 484 individuals. There were 138 *Sigmodon hispidus* individuals found. *P. gossypinus* and *S. hispidus* were cosmopolitan in distribution, occurring on all eleven and ten of eleven sites, respectively. *Ochrotomys nuttalli* was the fourth most common species with 60 individuals or 4.9% of total captures. Most golden mice (n=39) were caught at the USF Eco Area. There were nine shrew captures during the course of this study (shrews were not individually marked or identified to species). Other species documented, each with 3 or fewer individuals, were *Peromyscus polionotus, Didelphis virginia, Rattus rattus* (not native), *Neotoma floridana, Mus musculus* (not native), *Sciurus carolinensis*, and *Glaucomys volans*.

The distribution of species differed between sites where *Ochrotomys nuttalli* was present and that of all sites combined (Figure 7). Although *Podomys floridanus* was slightly more common overall than *Peromyscus gossypinus*, when only sites where *O. nuttalli* were captured are considered, the relative abundance of *P. gossypinus* (n = 324) is greater than that of *P. floridanus* (n = 191).
Discussion

*Ochrotomys nuttalli* displays a geographic range that is closely tied to the distribution of hardwood-containing habitats in Florida. These habitats are naturally fragmented and are becoming increasingly so under recent land use changes. This study suggests that the extent of occurrence of *O. nuttalli* remains relatively unchanged from historic records, but isolated populations of golden mice are vulnerable to extirpation as a result of extensive habitat fragmentation. A few historic populations are likely already extinct. Data from temporal trapping reveals that *O. nuttalli* were able to be captured during all months in which statewide presence/absence surveys took place, but peak abundances occur February through May. When focusing trapping on the thickest habitats available on each study site, *Ochrotomys nuttalli* were the fourth most abundant of eleven small mammal species captured.

This project describes the close alignment of *Ochrotomys nuttalli* locality data with the distribution of hardwood habitats in Florida. Hardwood-containing habitats are naturally fragmented, especially near the periphery of *O. nuttalli’s* range. Some suitable habitats, such as those on the Atlantic Coastal Ridge, are separated from other hardwood areas by a considerable distance. This situation suggests that there is little movement of golden mice between non-continuous hardwood areas. Mitochondrial sequence data from *O. nuttalli* support this claim, showing a high degree of structure between disjunct populations (Smiley et al., in review). In fact, populations on the Atlantic Coastal Ridge
appear to be on an independent evolutionary trajectory from other populations in Florida (Smiley et al., in review). Smiley et al. also found that southern periphery populations contain unique haplotypes not found elsewhere. This information is somewhat distressing given the highly isolated nature of some *O. nuttalli* populations and the pace of development in Florida. For example, as the north-south dispersal corridor is broken for populations inhabiting the Atlantic Coastal Ridge, individuals will not be able to colonize formerly occupied patches if extirpated by fire or some other disturbance.

The historic range map developed using GIS shows that *Ochrotomys nuttalli* have not been documented in all regions of Florida which it suggests they should occur. Additional trapping is needed, especially in central and north Florida to determine if *O. nuttalli* is present here. Also, while *O. nuttalli* occur near the limit of hardwood habitats in the western and central parts of the Florida peninsula, hardwood habitat on the east coast Atlantic Coastal Ridge continues well south of documented populations. Despite high levels of development on some stretches of the east coast of Florida, it is possible that *O. nuttalli* populations do occur further south. For example, arboreal nests likely made by golden mice were seen at Brevard County’s Valkaria-Grant Scrub Sanctuary, a few kilometers south of Malabar Scrub. However, the presence of arsonist-ignited wildfires in the area prevented live trapping at the time when nests were identified. If Brevard County is in fact as far south as *O. nuttali* extend on the east coast, one explanation for a range limit in this area is that forests begin to shift from temperate to mixed temperate and tropical species along this stretch of coastline.

As arboreal nests were present on all but one study site where golden mice were trapped, they seem to be a good indicator of *O. nuttalli*’s presence. Nest searching could
be utilized if circumstances do not permit the use of live traps. Nest searching is not a new technique as Ivey (1949) collected golden mice only from arboreal nests in his natural history study. If using nests as an indicator of presence, it is important to note that arboreal nests may remain intact for greater than a year after being deserted by *O. nuttalli* (Ivey 1949). The utility of nest searching could be limited if structures of similar appearance are in fact made by other species.

Although occurrence records aligned well with hardwood-containing habitats, some fell outside this habitat category. This condition can be explained in several ways: 1) error in the geographical data, 2) fluctuation in distribution of hardwoods based on land management practices, and 3) *Ochrotomys nuttalli*’s use of marginal habitats such as pine flatwoods. Error could occur in the locality data from an incorrect assignment of latitude and longitude coordinates to a specimen collection point. The Florida Museum of Natural History uses the georeferencing software GEOlocate which was developed at Tulane University ([http://www.museum.tulane.edu/geolocate/](http://www.museum.tulane.edu/geolocate/)) to assign latitude and longitude coordinates to museum specimens. If a museum label does not provide a thorough description of the point of collection, the software could assign an incorrect location to this specimen. Also, some degree of error is inevitably involved in categorizing regions of a state into one of several habitat types.

In the fire-maintained habitats of Florida the vegetation species composition of a particular area is likely to change with land management practices. Suppression of fire in pine flatwoods often leads to hardwood encroachment (Abrahamson and Hartnett 1990). Thus, the current distribution of hardwoods at a small scale may differ in some areas of Florida compared to their 1967 distribution if fire has been excluded. Fire suppression
occurs most often in small parcels of wildlands in close proximity to developed areas. This situation is often the case with county-owned properties.

Lastly, not enough is known concerning the biology of *Ochrotomys nuttalli* to justify that they do not occasionally make use of pine flatwoods habitat. To the contrary, when population abundances were high, individuals of *O. nuttalli* were captured at the USF Eco Area in areas of pine flatwoods (Smiley, unpublished data), albeit not far from more characteristic microhabitat. In addition, in the absence of fire, saw palmetto can become thick and grow to mid-story heights, possibly providing refuge for golden mice in the absence of shrubby hardwoods. More research is needed to determine what, besides the structure of the vegetation, may limit *O. nuttalli* to hardwood habitats.

The latitudinal extent of *Ochrotomys nuttalli*’s occurrence has not contracted in Florida, however two peripheral study sites where golden mice where not captured indicate the susceptibility of this species to land use change and land management practices. These locales are Melbourne Beach and Archbold Biological Station. Melbourne Beach has undergone a great deal of land use change since the collection of an *O. nuttalli* specimen here in 1945, although the Melbourne Beach region has fared better than regions to the south in terms of amount of development. The importance of this stretch of coastline to marine sea turtle nesting has driven conservation efforts, including the establishment of the Archie Carr National Wildlife Refuge. Despite this, remaining natural areas, particularly of scrub and hardwood hammock, are scattered in distribution and small in total size. Trapping data provided by this study and the minimal amount of remaining suitable habitat are strong indicators that *O. nuttalli* is absence in this area. However, further trapping is needed to confirm this assertion.
At Archbold Biological Station the potential absence of *Ochrotomys nuttalli* is mainly driven by land management practices. The combined effect of an increased fire regime to benefit Florida scrub jays (*Aphelocoma coerulescens*) on one side of the property and two seasons of intensive hurricanes (2004-2005) greatly altering habitat by knocking down canopy sand pines on the long-unburned Red Hill side of the station (F. Lohrer, personal communication) has resulted in the potential absence of *O. nuttalli* at this study site. No golden mice were captured at Archbold despite the greatest amount of effort invested here and continual preservation of the land. Only the presence of unoccupied arboreal nests and a reported capture by H. Hoffman at Lake Placid Scrub, just north of Archbold Biological Station, suggest that *O. nuttalli* are still present in the area. An alternative explanation for the absence of *O. nuttalli* on this study site centers on the high abundance of Florida mice (*Podomys floridanus*) on station. At Archbold, 301 *Podomys floridanus* individuals were caught 449 times with an effort of 976 trap nights. Such high numbers of *Podomys floridanus* could possibly drive down abundances of other competing small mammals or simply occupy traps. However, correcting effort for trap closures at this study still resulted in an effort that greatly surpasses first captures on sites where *O. nuttalli* were observed. Although high abundances of Florida mice themselves might help explain the absence of *O. nuttalli* at ABS, this explanation is not independent of land management practices as numbers of *Podomys floridanus* decline with fire suppression (Jones and Layne 1993).

Temporal changes in abundance and the timing of unmarked individuals entering the population at the USF Ecological Research Area point towards a mid-winter to spring breeding season of *Ochrotomys nuttalli* in south-central Florida. Two additional
observations lend support to this conclusion. First, a trap mortality caught on 29 January at Little Manatee River Southfork Tract in north Manatee County had 2 embryos present when prepped at the museum (Florida Museum of Natural History specimen number UF31664). Second, a female golden mouse that was flushed from an arboreal nest on 27 February at Indian Mounds in north Brevard County had two suckling young attached to her (Smiley, person observation). When taken together, these data point toward a late January to May breeding season for *O. nuttalli* in south-central Florida.

Data from this study both support and contradict other information available in the literature concerning the breeding season of southern *Ochrotomys nuttalli* populations. Pearson (1953) reported higher abundances of golden mice from January through May in comparison to the remainder of the year from live trapping in Gulf Hammock, Florida. In Texas, mature golden mice have been reported in breeding condition in January and February (McCarley 1958). In contrast, Ivey (1949) reported a female with suckling young and four embryos on 3 November in eastern Florida and young about one week of age on 21 December, suggesting an October to December breeding season. Also in partial disagreement with the present study, Layne (1960) reports *O. nuttalli* litters born in June and July, pregnant and lactating females in July, September, and November, as well as a female with newborn young on the 2 March. Layne’s (1960) observations in central Florida point toward a longer eight to nine month breeding season than the five to six month season suggested by the present study. The discordance among breeding season data suggest that a factor besides season may regulate breeding times in southern populations of *O. nuttalli*. 

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When trapping in the thickest habitats available on each study site, *Ochrotomys nuttalli* was the fourth most abundant of twelve species captured (with all shrews potentially erroneously lumped into one species). However, some qualification is needed for a few of the more uncommon species. Two species, the Virginia opossum (*Didelphis virginia*) and the grey squirrel (*Sciurus carolinensis*), are typically too large to physically fit in Sherman live traps. Thus, these captures should not be taken as a true indicator of abundance for these species. Grey squirrels were indeed seen more than they were captured and the trap that captured a grey squirrel had to be physically dismantled to release the large animal (Smiley, personal observation). Two other species, the black rat (*Rattus rattus*) and the house mouse (*Mus musculus*), are not native to Florida and seldom reach high densities outside of urban areas. This result leaves *O. nuttalli* as the fourth most abundant of eight species. In habitats with a thick understory to mid-story, one would not expect to find high abundances of oldfield mice (*Peromyscus polionotus*) which prefer more open areas or southern flying squirrels (*Glaucomys volans*) which would encounter trouble gliding through thick scrub. Thus, of species that typically occur in thick habitats, only shrews and the wood rat (*Neotoma floridana*) are less abundant than *O. nuttalli*. The only captured species that is categorized in the state of Florida as imperiled under the designation of Species of Special Concern because of significant vulnerability to habitat modification is the Florida mouse (*Podomys floridanaus*). The Florida mouse was also the species of greatest abundance in this study, but was not found on all study sites. It is not possible to give density estimates for *O. nuttalli* from this research with which to compare to the literature as trapping was not carried out on established grids.
The distribution of species differed between sites where *Ochrotomys nuttalli* was present and that of all sites combined. This difference is caused by the fact that *Podomys floridanus* can reach very high abundances on study sites that are managed to be relatively open, a situation which typically leads to lower *O. nuttalli* abundances. The removal of just one study site, Archbold Biological Station where 301 *Podomys floridanus* individuals were caught, changes the species abundance rankings and makes ‘present’ sites closer in species distribution to those places where *O. nuttalli* was not captured. My data should not be taken as evidence that preserve managers must make a choice between maintaining Florida mice versus golden mice on their properties. To the contrary, several scrub sites including SWFWMD’s Jack Creek and Little Manatee River Southfork Tract contain heterogenous scrub habitat – managed to be open and of low height in some portions and with taller thickets of scrub oaks in other areas of the site – a management strategy that seems to be able to support both species given a minimal preserve size. *Ochrotomys nuttalli* and *Podomys floridanus* represent only two of the numerous species that have adapted to living in different subsets of the various successional stages of scrub, a habitat that historically burned every 10 to 100 years (Myers, 1990). The best option for maintaining multiple species would be to protect large areas of land from development. As large tracts of scrub have already been converted to other land uses, the reality of this option is limited. The second best option for maintaining multiple species with different habitat requirements on preserves may be to manage these properties in a way so that they maintain the heterogenous nature of the historic landscape. If hardwoods habitats in Florida are managed exclusively for those
species adapted to frequent fires, then the future persistence of *O. nuttalli* in the remaining hardwood habitat patches of south-central Florida may be bleak.

Several of the parcels of land where golden mice were easily captured in this study contain patches of habitat that have not burned for decades. As the attitudes of land managers shift from one of fire exclusion to that of active management, many of these properties are undergoing tremendous alterations. After so many years of fire exclusion, fire-dependent species may no longer be present on these properties, especially if preserves are small in size. Land managers should set clear goals for their management techniques. In the case of scrub, managers might aim for manipulating the land until it has the visual characteristics of ideal scrub habitat, but in doing so they should realize that the biodiversity of their property may decline as species that are adapted to overgrown conditions go locally extinct and those adapted to open conditions are unable to colonize the property because of habitat fragmentation. These consequences should be considered when making management decisions.
Figure 1. Probable historic distribution of *Ochrotomys nuttalli floridanus*. Locality records align with the distribution of hardwood-containing habitats. See text for detailed description of habitat classification.
Figure 2. A probable current distribution of *Ochrotomys nuttalli* with focus on south-central Florida where historically populations were the most naturally fragmented. Removal of select anthropogenic land uses creates a landscape where hardwood-containing habitats are even more isolated from one another. Populations evaluated during 2007-2008 are identified based on the category they best fall into based on direct trapping evidence: Confirmed Present: *O. nuttalli* caught on site, Determined Absent: *O. nuttalli* not captured on site, and Not Assessed: site status not evaluated by the present study. Marginal habitat is not shown here for sake of clarity.
Figure 3. Layout of the sixty trap stations operated at the USF Ecological Research Area.

Stations were spaced at least 10 meters apart in areas where *O. nuttalli* had been previously captured. Two traps were set at each station.
Figure 4. The locations of the fourteen study sites on which trapping occurred in search of *Ochrotomys nuttalli*. Locales sampled included: USF Ecological Research Area (ECO), Balm-Boyette Scrub (BBS), Little Manatee River Southfork (LMRSF), Wekiwa Springs State Park (WSSP), Tiger Creek (TC), Jack Creek (JC), Archbold Biological Station (ABS), Faver-Dykes State Park (FDSP), Indian Mounds (IM), Malabar Scrub (MS), south Melbourne Beach (MB), Deep Creek (DC), Shell Creek (SC), and Hickey’s Creek Mitigation Park (HC).
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<th># Trap Nights</th>
<th>Dates of Trapping</th>
<th>O. nuttalli caught?</th>
<th>O. nuttalli capture rate</th>
<th>O. nuttalli corrected capture rate</th>
<th>O. nuttalli nests present?</th>
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Table 1. Capture success of *Ochrotomys nuttalli* at the eleven sites within the documented range of this species during 2007 and 2008. Capture rates reflect the number of captures (including recaptures) divided by number of trap nights. Corrected capture rates was computed similarly (number of captures/corrected trap nights), but with corrected trap nights calculated by the total number of trap nights minus the product of the number of traps closed in the morning that did not contain *O. nuttalli* times one half. Shading indicates sites where *O. nuttalli* were not caught, but nests were seen (light grey) or those sites where nests were not observed and golden mice were not caught (dark grey). Asterisks (*) indicate previously undescribed locations were *O. nuttalli* were captured.
Figure 5. The percentage of ‘present’ trapping periods which resulted in a capture of *Ochrotomys nuttalli* by a given level of uncorrected (A) and corrected (B) effort.
<table>
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<tr>
<th>Site</th>
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<th>Corrected Effort</th>
<th>% Trapping periods below</th>
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Table 2. Effort on ‘absent’ study sites and the proportion of ‘present’ sites with a first *Ochrotomys nuttalli* capture before the amount of effort at each ‘absent’ site.
Figure 6. Abundance of *Ochrotomys nuttalli* over time based on the number of individuals captured each trap period at the USF Eco Area.
Figure 7. Relative abundance of small mammal species captured in Sherman live traps at the eleven locales within the documented geographic range of *Ochrotomys nuttalli*. Each category of sites graphed is a subset of the previous bar graph group. ‘Present’ sites are those on which *O. nuttalli* were captured. Species codes are as follows: PFL = *Podomys floridanus*, PGO = *Peromyscus gossypinus*, SHI = *Sigmodon hispidus*, ONU = *Ochrotomys nuttalli*, SHR = Shrew sp., PPO = *Peromyscus polionotus*, DVI = *Didelphis virginia*, RRA = *Rattus rattus*, NFL = *Neotoma floridana*, MMU = *Mus musculus*, SCA = *Sciurus carolinensis*, and GVO = *Glaucomys volans*. 
Literature Cited


